MAPPING KAOLINITE AND GIBBSITE OF BRAZILIAN TROPICAL SOILS USING IMAGING SPECTROMETRY DATA (AVIRIS)

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1. INTRODUCTION

Tropical soils are very weathered due to the severe climatic regimes they were submitted in the forming process. The clay fraction is composed basically by iron oxides (hematite and goethite), aluminum oxides (gibbsite), and 1:1 clay minerals (kaolinite).

The molecular ratio of SiO_2 and Al_2O_3, or Ki value is usually used as a soils weathering degree indicator and for these strongly weathered soils, Ki is essentially a measure of the kaolinite and gibbsite proportions.

Kaolinite and gibbsite present characteristic features in the reflectance spectra. Recently it was demonstrated that arithmetic relationships obtained from certain extracted parameters of those spectra keep narrow relationship with the values of Ki (Madeira Netto et al., 1995). Baptista et al. (1998a) has shown a similar approach for the AVIRIS data. Clark et al (1990) have presented an algorithm that allows the estimation of mineral abundance in AVIRIS data.

The data obtained by the hyperspectral sensors, especially AVIRIS (Airborne Visible/InfraRed Imaging Spectrometer, JPL/NASA), present a spectral resolution compatible with kaolinite (2205 nm) and gibbsite (2265 nm) features (Baptista et al., 1998b) and therefore they can allow to estimate the weathering degree of soils. The aim of this work is to use imaging spectrometer data to map kaolinite and gibbsite abundance and the Ki value for tropical soils.

2. THE MOLECULAR RATIO OF SiO_2 AND Al_2O_3

The pedogenesis of highly weathered soils , as the latossolos, is characterized by silica and bases removal and accumulation of aluminum. The molecular ratio of SiO_2 and Al_2O_3 is considered as a weathering index and is given by the following expression (1):

$$Ki = \frac{\lfloor SiO_2 \rfloor}{\lfloor Al_2O_3 \rfloor} \tag{1}$$

Low Ki values, indicate more weathered soils, due to partial or total removal of the silica and posterior concentration of the aluminum. For the highly weathered soils kaolinite and gibbsite are essentially the minerals that influence the values assumed by Ki. The kaolinite presents in its chemical composition silica and aluminum, while the gibbsite presents aluminum.

Madeira Netto (1993) developed a relationship between the points of inflection of the spectral features of those two minerals, associated to the point of maximum reflectance located between the two features, more specifically to 2225 nm, according to figure 1.

That point of maximum reflectance between the features is considered as the reference for measuring of the intensity of absorption of the two minerals and these are calculated by means of the following expressions:

$$I_{kaol} = R\max - R_{2205} \quad (2)$$

$$I_{gib} = R\max - R_{2265} \quad (3)$$

Where Ikaol is the intensity of absorption of the kaolinite, Igib is the intensity of absorption of the gibbsite, Rmax is the point of maximum reflectance between the features of absorption of the two minerals, R2205 and R2265 are the values of the reflectance at 2205 and 2265 nm, respectively (Madeira Netto et al., 1995).

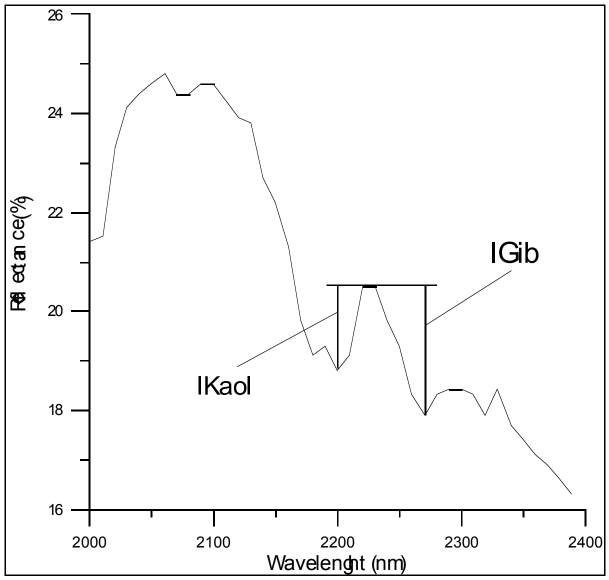

Figure 1 - Diffuse reflectance spectra (2000 to 2400 nm) of a soil sample. Adapted of Madeira Netto et al. (1995).

An index, IKi, can be calculated that is proportional to the molecular relationship Ki. Madeira Netto et al. (1995) determined the following relationship for the determination of IKi (4).

$$IKi = \frac{I_{kaol}}{\left(I_{kaol} + I_{gib}\right)} \quad (4)$$

For 53 samples of soils with great weathering variability the values of IKi and Ki presented high correlation (r^2 = 0,98) (Madeira Netto et al., 1995).

3. STUDY AREA DESCRIPTION

The study area is located in the district of São João D'Aliança and it was one of the areas covered by the AVIRIS sensor, in 1995, in the mission SCAR-B (Smoke, Clouds and Radiation - Brazil). That mission was accomplished due to the agreement between the Brazilian Space Agency (AEB), National Institute of Space Researches (INPE) and National Aeronautics and Space Administration (NASA), in the period of August to September of 1995, in the states of Goiás, Mato Grosso, Mato Grosso do Sul, Minas Gerais and Rondônia.

The image used in this work is part of 950816L2 sub scene 03 acquired in August 16, 1995, fly 02 (Figure 2).

At the data acquisition time the ground was not yet prepared for cultivation and still presented crop residues covering most of the soil surface. Even so, the sub scene presents a considerable continuous area of bare soils which allowed the accomplishment of this work.

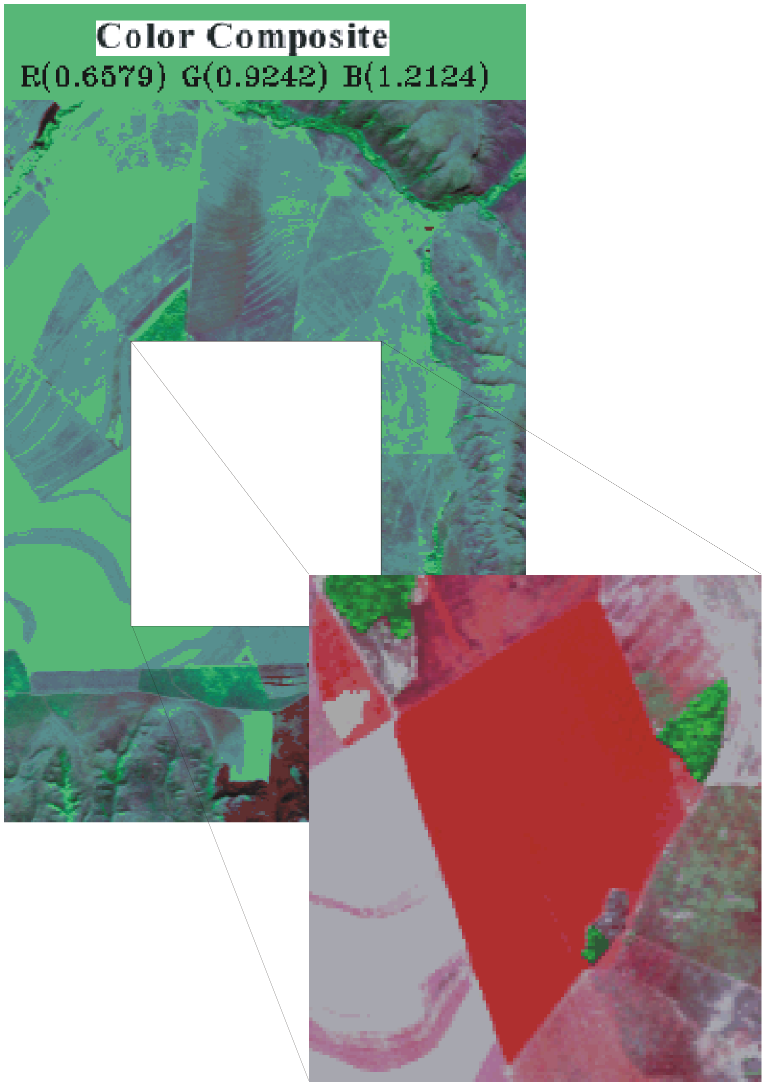

Figure 2 – View of the study area in the 950816L2-03 scene

The selected area is located at the top of a dome. The topography is flat to gently rolling with slopes varying from 0% to 4%. The soils are deep (more than 4 meters deep) clayey dark red latosols (Oxisols) developed from slate. A fracture system seems to be responsible for the kaolinite/gibbsite differentiation in the area.

Baptista et al. (1998b) showed the coherence between the spectra obtained in the AVIRIS data and that obtained in the laboratory with samples collected in the field, for kaolinite and gibbsite, in this same sub scene.

4. METHODOLOGY

The adopted procedure is based on four stages: atmospheric correction and reduction of AVIRIS radiance to scaled surface reflectance; mathematical handling of the images data for calculating IKi; use of ENVI's Spectral Feature Fitting module for kaolinite and gibbsite mapping; linear regression between the IKi and the SFF results.

4.1 ATMOSPHERIC CORRECTION AND REDUCTION OF AVIRIS RADIANCE TO SCALED SURFACE REFLECTANCE

This step was accomplished in INPE, in São José dos Campos, SP, using the method described in Green et al. (1991). That method is based on a calibration procedure of the parameters with data collected in the field, at the moment of its acquisition, and a model of radioactive transfer (MODTRAN).

The method has four steps (Robert O. Green, personal communication):

1) Developing look up tables for a range of atmospheric conditions with the MODTRAN radioactive transfer code.

2) Convolving the MODTRAN spectra to the AVIRIS spectral characteristics.

3) Deriving the atmospheric conditions from the AVIRIS spectra and the MODTRAN look up tables.(primarily water vapor).

4) Inverting the AVIRIS calibrated spectral radiance to apparent surface spectral reflectance.

According to Clark et al. (1995) that correction accomplishes an adjustment in the levels of oxygen, CO2 and vapor of water for each pixel, resulting, in the elimination of the absorption bands of the water at 1400 and 1900 nm, besides reducing the radiance data for reflectance.

4.2 MATHEMATICAL HANDLING OF THE IMAGES

The software ENVI® version 3.0 was used, in its modules band math, to calculate the equations 2, 3 and 4; interactive stretching, for enhancement of the results; density slicing, generation of the IKi map, and for segmentation of the resulting image.

In the band math module the following expression was adopted:

$$IKi = ((b_2 - b_1) / ((b_2 - b_1) + (b_2 - b_3))) \tag{5}$$

Where b1 = band 193 (2196,8 nm); b2 = band 196 (2226,6 nm); and b3 = band 200 (2266,3 nm). Those bands were adopted because are the ones that best approach the values used by Madeira Netto et al. (1995).

4.3 SPECTRAL FEATURE FITTING FOR KAOLINITE AND GIBBSITE MAPPING

The classification module SFF (Spectral Feature Fitting) of the software ENVI® was used for identifying the kaolinite and gibbsite rich areas. This procedure is based on the comparison between the spectra of each pixel with the reference spectra of the spectral library, by means of the least squares fit technique, in the 2100 to 2300 nm interval, which covers the features of the main minerals of tropical soils.

5. RESULTS AND DISCUSSION

After calculating the expression 5 by means of the band math module, the histogram was expanded by equalization, seeking a better perception of the variations in the values of IKi, as it can be visualized in the figure 3. The scale of colors used indicates the gradual variation of IKi in the image, with the smallest values being represented by the darker tonalities, and the largest values being represented by the clearer ones.

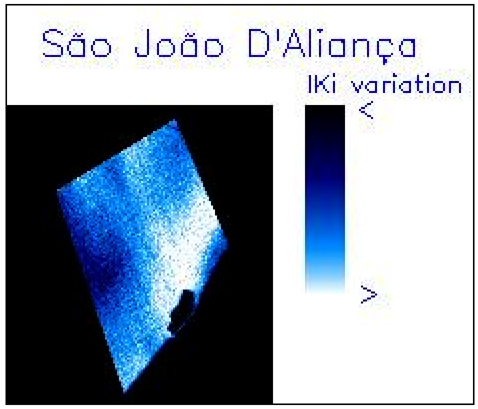

Figura 3 - IKi variation

After analysis of the IKi variation for the sub scene the *density slice* module was used for the slicing presented in the figure 4. For the areas with exposed soils the IKi values varied between 0,10 and 0,75. This variation interval is comparable to the values found by Madeira Netto et al. (1995) although the procedures used to obtain the reflectance values have been very different. It was adopted three intervals: 0,10 to 0,30; 0,30 to 0,50; and 0,50 to 0,75.

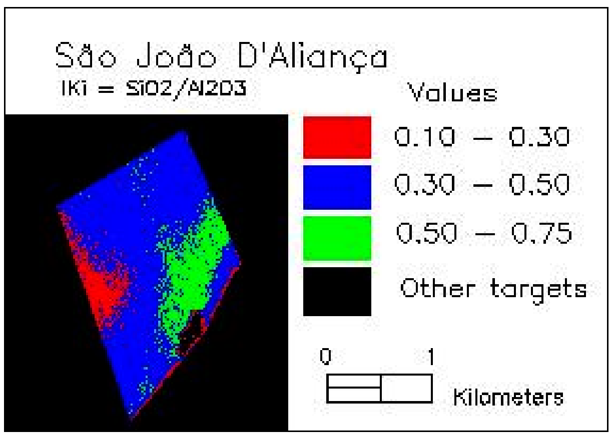

Figura 4 - IKi density slice

The spectra presented in the figure 5 illustrate those variations in the kaolinite and gibbsite proportions, for the three classes in the illustration 4. The proportional variations of the minerals by means of its absorption intensities are showed. In the class 0,10 <IKi <0,30 (Figure 5a) it is noticed that the gibbsite contents are high, as shown by intensity of its absorption band in 2265 nm. The spectrum that represents the class 0,30 <IKi <0,50 (Figure 5b) presents a smaller intensity of the band of absorption of the gibbsite, what demonstrates a certain balance between the proportions of this mineral with the kaolinite. Finally, the representative spectrum of the class 0,50 <IKi <0,75 shown on figure 5c illustrate the soils that are essentially kaolinitics, once the absence of the gibbsite feature is observed in this interval.

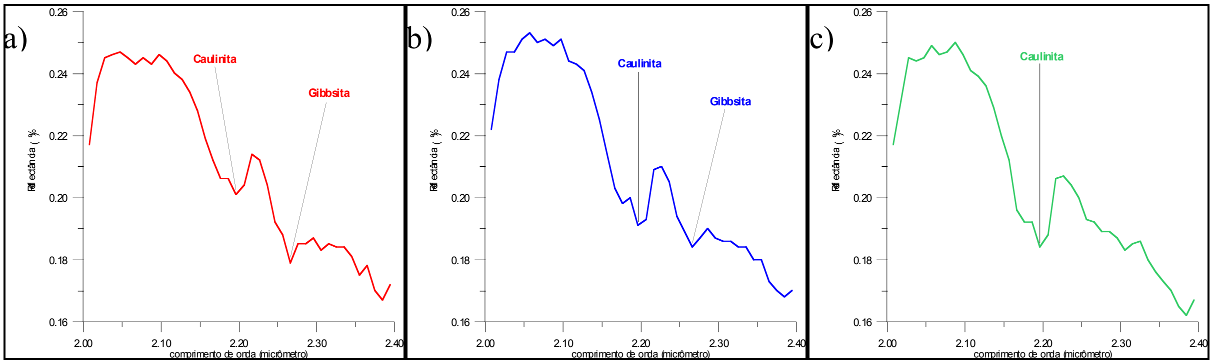

Figure 5 - Spectra of sites located inside of each one of the three classes of IKi, obtained from the AVIRIS data.

ENVI's Spectral Feature Fitting module was adopted, for the space individualization of kaolinite and gibbsite. The Kaolinite Well-Ordered PS-1A and the Gibbsite Synthetic OH-3A spectra of the JPL spectral library was used as endmembers for the accomplishment of the SFF classification. The AVIRIS image, and the reference spectra were normalized by continuum removal. The fit images which provide information about the two minerals abundance are presented in figures 6 and 7. We notice a trend for inverse abundance of kaolinite and gibbsite: the areas richer in gibbsite (white) are poorer in kaolinite (dark) and vice-versa. This is coherent with the forming process of these two mineral in the soils.

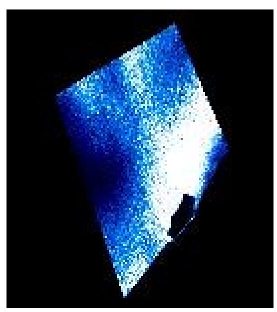

Figure 6 – Kaolinite Fit Image.

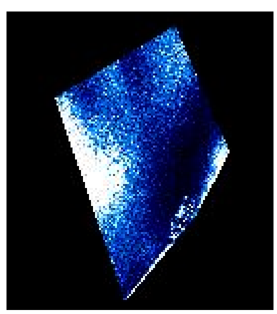

Figure 7 – Gibbsite Fit Image.

A ratio image (scale kaolinite)/(scale kaolinite +scale gibbsite) was also obtained. For the weathered latosols this ratio is a fair estimation of Ki. The obtained image is presented on figure 8. Compared to the IKi image we notice a good agreement between the two images.

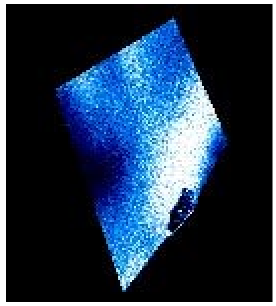

Figure 8 – Ratio image (scale kaolinite)/(scale kaolinite +scale gibbsite) .

To analyze the similarity of the IKi with Spectral Feature Fitting results, a linear regression analysis between the two images was done using the regression module of the software IDRISI® version 1.0 for windows. The result SFF being adopted as dependent variable and IKi as the independent variable. The obtained determination coefficient was quite high, ($r^2 = 0.96$) indicating that the two methods are appropriate for mapping the weathering stage of tropical soils. The figure 9 presents the linear regression between the two results.

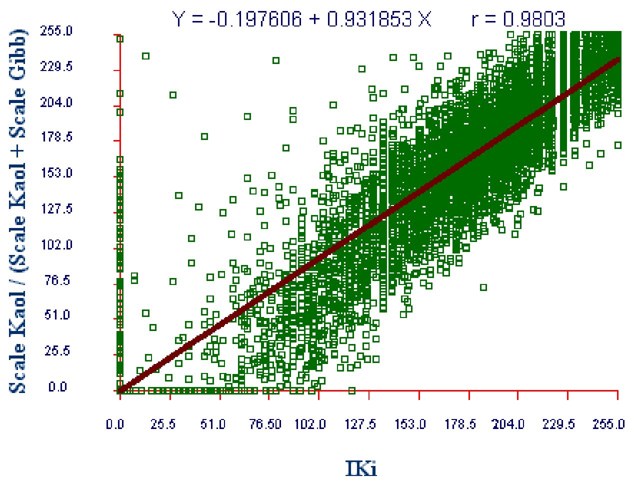

Figure 9: Linear regression between scale kaolinite/(scale kaolinite + scale gibbsite) and IKi

6. CONCLUSIONS

Kaolinite and gibbsite occurrence in the soils was investigated using the Spectral Feature Fitting algorithm. The results present trends that are coherent with the kaolinite/gibbsite variations usually observed in tropical soils. Quantitative mineralogical analysis of soil samples will be conducted and the results will be compared with spectral data.

A ratio image between kaolinite and gibbsite scale images were in close agreement with the IKi, being two alternative ways to estimate Ki values of tropical soils.

7. REFERENCES

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